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Evaluation of an Impending Pandora Moth, *Coloradia pandora pandora* Blake (Lepidoptera: Saturniidae), Outbreak on the Mammoth and Mono Lake Districts, Inyo National Forest, Mono County, California

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Background

In late June 2002, personnel from the Mammoth District, Inyo National Forest, noticed light defoliation on Jeffrey pine in various locations on both the Mammoth and Mono Lake Districts in Mono County, California. Subsequent detection surveys conducted by John Wenz, Entomologist, Forest Health Protection and Scott Kusumoto, Mammoth District, determined that the defoliation was due to feeding by larvae of the pandora moth, *Coloradia pandora pandora* Blake (Lepidoptera: Saturniidae) (Tuskes et al., 1996). The pandora moth is a periodic defoliator indigenous to western coniferous forests. Jeffrey, ponderosa and lodgepole pines are the primary hosts. An outbreak occurred previously on the Mammoth and Mono Lake Districts from 1978 to 1983. This report will 1) discuss the biology, ecology and outbreak history of the pandora moth; 2) assess the current situation; 3) address what may occur over the next few years; and 4) discuss potential management alternatives.

Biology

Moths in the family Saturniidae are commonly called giant silk moths or wild silk moths due to the silken cocoons produced by the larvae of many species. In addition to the pandora moth, there are three other *Coloradia* species and one subspecies that occur north of Mexico (Tuskes et al., 1996). These are *C. doris* (Utah, Wyoming and parts of Idaho, Montana, Colorado, New Mexico, Arizona and Nevada), *C. luski* (parts of Utah, Colorado, Arizona and New Mexico), *C. velda* (southern California) and *C. coloradia davisi* (parts of Utah, Arizona, New Mexico and Texas). The pandora moth occurs in parts of California, Oregon, Nevada, Utah, Idaho, Colorado, Wyoming, South Dakota and Nebraska.

The pandora moth usually has a two year life cycle, taking 24 months to complete one generation (Keen, 1952: Carolin and Knopf, 1968; Furniss and Carolin, 1977). A small proportion of a given population may take three or more years to complete a cycle due to extended pupal diapuse (Gerson et al., 1999). Adults are large, heavy-bodied moths, about 1 to 1 ½ inches long with a wingspan of 3 to 4 ½ inches. Adult females tend to be slightly larger than males. Wings are brownish to pinkish gray. Each wing is marked with a black dot and a darkish wavy line. Adult males have conspicuous feathery antennae (quadripectinate) while female antennae are more slender and threadlike (bipectinate).

Adults emerge from pupal cases in the soil from late-June through September, with peak emergence and flight between late-July and mid-August (Carolin and Knopf, 1968; Schmid, 1984; Ross, 1996; Gerson et al., 1999). Adults live five to ten days, have vestigial mouthparts and do not feed. Most flight activity occurs at night but some flight activity has been observed during the day under outbreak-level population conditions (Tuskes et al., 1996). Flight distance capability for individual moths is not known but has been estimated at between four and ten miles (Schmid and Bennett, 1988). Adults are strongly attracted to lights, especially ultraviolet radiation, and during flight years often congregate in large numbers around light sources. Adult moths can be so numerous as to cause short-term disruption of normal activities, crawling onto people, personal belongings, vehicles, buildings, roadways and parking areas. Large

concentrations of moths have caused the cancellation of tennis games and the temporary closing of facilities (Schmid and Bennett, 1988).

Following emergence from the pupae, adults crawl up through the soil and litter and migrate over the litter surface until they find a vertical object (vegetation, tree bole, stump etc.) which they then climb (Schmid, 1984). Female adults produce a sex pheromone from a specialized gland located at the tip of the abdomen. The pheromone has been identified as a mixture of *E*10,Z12-hexadecadienal, *E*10,Z12-hexadecadienyl acetate, and *E*10,*E*12-hexadecadienyl acetate (McElfresh et al., 2000). Mating often occurs soon after emergence. Eggs are globular, about $1/10^{th}$ inch in length, and range in color from bluish green to bluish gray. Female moths produce an average of 145 to 153 eggs/female with a range of 108 to 188 eggs/female (Wygant, 1941; Schmid and Bennett, 1988). Eggs are sometimes laid individually, but are usually deposited in clusters that range from 2 to 50 eggs/cluster and average between 10 and 20 eggs/cluster. Eggs are often laid on the bark and foliage of host pines, but during outbreak conditions, can also be deposited on a variety of surfaces including the forest floor, rocks, brush, vehicles, buildings and light poles, the latter reflecting the tendency of adults to be attracted to light (Schmid and Bennett, 1988).

Most of the eggs are laid in July and August. The eggs hatch after about 21 to 50 days into first stage larvae about ¼ inch long with shiny black heads and black spines on the body. There are five larval stages. Larvae feed primarily on Jeffrey, ponderosa and lodgepole pines. Coulter pine and sugar pine are also recorded hosts (Carolin and Knopf, 1968). First and second stage larvae tend to feed in groups until fall when they often disperse and feed individually. Second and third stage larvae overwinter at the base of needles but may do some feeding during the winter when daytime temperatures are warm enough. The larvae grow rapidly the following spring as temperatures become favorable and consume increasingly large amounts of foliage. The final, fifth stage larvae, are about 2 ¼ to 3 inches in length and have orange-brown heads. The bodies have short dark spines and are blackish at first and then change to olive brown with transverse yellow bands and a longitudinal white stripe.

Depending on the year and geographical location, larval feeding can begin as early as April and continue into June and early-July. When fully grown in June or early-July, the larvae migrate down the tree boles and enter the soil to pupate and overwinter. Pupae are 1 to 1 ½ inches in length, dark reddish to purplish brown with a tough outer shell. The pupae are not enclosed in a cocoon but are formed in loose cells of silk and debris in the soil from one to five inches below the surface. Areas with loose mineral soil appear most favorable for pupation (Wygant, 1941; Keen, 1952). Pupae tend to be more abundant under relatively open crowns and in areas where the depth of the forest floor (all material above the mineral soil) is least, especially in locations where the forest floor depth is less than 1 ½ inches (Miller and Wagner, 1984). Most diapausing pupae overwinter in the soil for 12 to 13 months until the following summer when the adults emerge. A small proportion of the pupae may remain in the soil for two or more years but the rate of successful adult emergence from these pupae is very low (Massey, 1940; Carolin, 1971; Gerson et al., 1999). Since most pupae emerge after one year in the soil, adult flight is usually concentrated during one summer with relatively few adult moths flying in the "off" year.

Pandora moth larvae are considered a traditional food source among native Americans, including the Klamath Indians and the Owens Valley-Mono Lake Paiutes (Aldrich, 1912; 1921; Blake and Wagner, 1987; Fowler and Walter, 1985; Patterson, 1929; Weaver and Basgall, 1986). The Klamath and Modoc Indians are reported to also use pupae as food (Patterson, 1929).

Natural Mortality Factors

Several biotic and abiotic mortality factors interact with pandora moth populations. Biotic factors include an entomopathogen (virus), vertebrate predators and invertebrate parasitoids. Abiotic factors include temperature extremes and fire.

A nuclear polyhedrosis virus has been identified from the pandora moth (Hughes, 1977). This virus or "wilt disease" has been associated with the collapse of several pandora moth outbreaks (Patterson, 1929; Wygant, 1941; USDA Forest Service, 1981a; Schmid and Bennett, 1988; Wickman et al., 1996). Although the process is not well understood, the virus apparently remains viable in the environment between outbreaks. As pandora moth populations increase over multiple generations, the virus spreads and builds up (epizootic) to levels that can cause considerable mortality. Viral infection levels of 48 to 94 percent of the larvae have been reported in declining pandora moth outbreak populations (Wygant, 1941; USDA, 1982; Schmid and Bennett, 1988).

A number of vertebrate predators feed on the pandora moth. Rodents, including ground squirrels (*Spermophilus sp.),* specifically the golden-mantled ground squirrel (*S. lateralis*), the Kaibab ground squirrel (*S. aberti kaibabensis*), the deer mouse (*Peromyscus maniculatus*) and chipmunks (*Tamias sp.*) feed on pupae in the soil (Patterson, 1929; Schmid and Bennett, 1988; Gerson et al., 1999). Wygant (1941) asserted that bears also feed on pandora moth pupae. In addition to pupae, golden-mantled ground squirrels feed on adult moths but not eggs, apparently due to a physical inhibition induced by the tough eggshell (Gerson et al., 1998). American robins (*Turdus migratorius*) have also been observed feeding on adults and viable eggs have been found in robin feces (Carolin and Knopf, 1968; Schmid and Bennett, 1988). Brown creepers (*Certhia americana*) and nuthatches (*Sitta sp.*) feed on pandora moth eggs and Steller's jays (*Cyanocitta stelleri*) and vireos (*Vireo sp.*) feed on larvae (Carolin and Knopf, 1968).

Insect parasitoids in the Hymenoptera and Diptera also utilize the pandora moth. Several hymenopterous parasitoids have been recorded from pandora moth eggs including *Trichogramma minutum* (Trichogrammatidae); *Telenomus sp.* (Scelionidae); and *Tetrasticus sp.* (Eulophidae) (Patterson, 1929; Schmid and Bennett, 1988). In addition, parasitoids tentatively identified as *Anastatus furnissi* (Eupelmidae), two genera of Eulophidae and an Encyrtidae, were reared from pandora moth eggs during the 1978 to1983 outbreak in Mono County (CFPCAC, 1982). Two other hymenoptera attack pandora moth larvae: *Apanteles sp.* (Braconidae) and *Hemiteles tenellus* (Ichneumonidae) (Wygant, 1941; Patterson, 1929.)

Tachinid flies, one unidentified (Schmid and Bennett, 1988) and one identified as *Blepharipeza adusta* (Patterson, 1929) have also been recorded as parasitizing pandora moth larvae. One parasite, *Cratichneumon unifasciatorius* (Ichneumonidae) has been reared from pandora moth pupae (Schmid and Bennett, 1988). Tuskes et al. (1996), lists the following parasitioids from the pandora moth: *Compsilura concinnata* and *Leschenaultia adusta* (Tachinidae); *Anastatus furnissi, Tetrastichus pandora* and *Trichogramma minutum* (Chalcidoidea); *Cotesia electrae* (Braconidae) and *Gelis tenellus* (Ichneumonidae).

Both high and low temperatures have been associated with pandora moth larval mortality (Wygant, 1941). Although exact temperatures were not documented, larval mortality estimated to be at least 50% of the overwintering population were observed in northern Colorado during the winter of 1938-1939. An unofficial temperature of -40 degrees F was recorded in a valley about 11 miles from the outbreak. In July 1939, during the same outbreak in Colorado, high temperatures were implicated in mortality to migrating larvae attempting to enter the soil to pupate. A limited study estimated larval mortality attributed to high temperatures to average 43% (34% to 55%). Soil surface temperatures near dead larvae ranged from 138 degrees F to 142 degrees F while temperatures one-half inch below the surface ranged from 124 degrees F to 135 degrees F. Temperatures of 102 degrees F and 100 degrees F did not seem to inhibit larvae from burrowing into the soil. Interactions among factors that might influence successful pupation, including microclimatic variables (e.g., temperature, moisture and soil bulk density) and factors that could affect the condition of individual larvae, have not been examined.

Fire can also function as a mortality agent affecting pandora moth populations. Keen (1952) reported that smoke and heat from a prescribed burn in the fall of 1922 caused pandora moth larvae to drop to the ground where they were "destroyed". Gerson and Kelsey (1997) have shown that a nocturnal summer prescribed fire can cause mortality to flying pandora moth adults as they are attracted to light from the fire. The biological characteristic of spending 12 to 13 months in the upper layers of the soil make pandora moth pupae potentially susceptible to lethal temperatures generated by naturally occurring or prescribed ground fire. Schmid et al. (1981) and Schmid and Bennett (1988) have demonstrated that prescribed fires can kill pandora moth pupae in the soil where litter depth is sufficient to sustain temperatures hot enough to kill the pupae. The influence of fire, occurring under natural fire regimes in pine ecosystems containing pandora moth hosts, on pandora moth population dynamics is conjectural. Miller and Wagner (1984) speculated that the tendency for pandora moth larvae to pupate in the soil in relatively open areas with low levels of forest floor cover (reduced fuels) is an adaptation to the presumed frequent, low-intensity, natural fire regime.

There have been no comprehensive studies of pandora moth population dynamics. Relatively high levels of the nuclear polyhedrosis virus have been associated with declining pandora moth outbreak populations, but the interactive effects of the natural enemy complex on outbreak-level population dynamics has not been quantified. The roles of the various biotic and abiotic factors in maintaining pandora moth populations at endemic levels and how they interact with pandora moth populations in the interval between outbreaks is not known.

Outbreak History

Several pandora moth outbreaks have occurred in the western United States since the 1890's. The earliest known outbreak occurred on the Klamath Indian Reservation in south-central Oregon just prior to 1893 (Carolin and Knopf, 1968). Subsequent outbreaks have occurred in south-central Oregon, 1918 to 1925 (Chamberlin, 1922; Patterson, 1929); north-central Colorado, 1937 to 1939 (Wygant, 1941); Utah, Colorado and Wyoming, 1959 to 1966 (Carolin and Knopf, 1968); central Oregon, 1963 to 1968 (Carolin and Knopf, 1968); north-central Arizona, 1978 to1984 (Brown, 1984; Schmid and Bennett, 1988); and south-central Oregon, between Bend and Klamath Falls, 1988 to the present (Mitchell, 1989; Wickman et al., 1996; A. Eglitis, pers. com., 2002). The current outbreak in south-central Oregon started near Bend in 1988. Since then, defoliation has occurred every year trending in a southerly direction toward Klamath Falls. While some defoliation has occurred every year since 1988, pandora moth activity in specific stands has only lasted six to eight years or three to four generations. Most of the 2002 activity occurred in areas east of Chiloquin.

California. There have been four documented pandora moth outbreaks in California since the late 1950's. The first three occurred from 1959 to 1966 (USDA, 1960; CFPCAC Pest Conditions Reports, 1964 to 1967) and the fourth from 1978 to 1983 (CFPCAC, 1979 to 1984). There have also been several reports of "incidental" pandora moth activity. Based on studies of Native American customs, it is very likely that unrecorded pandora moth outbreaks have occurred in California, particularly in the Mono Lake area (Aldrich, 1912; 1921; Weaver and Basgall, 1986; Blake and Wagner, 1987). Documentation of the 1959 to 1966 outbreaks is minimal but indicates that the pandora moth was active in three different locations during this time period.

San Diego County: 1959 to1964. Larval feeding on Jeffrey pine was reported in San Diego County in 1960 from the West Mesa area in Cuyamaca Rancho State Park, south of the community of Julian, and in the vicinity of Mt. Laguna on the Descanso District, Cleveland NF (USDA, 1960). Late-stage larvae were observed in April and May of 1960 suggesting adult flight and egg deposition in 1959. Reference to this outbreak continuing at low levels was made in the 1963 and 1964 Pest Conditions Reports, implying that there was also activity in 1961 and 1962 although there was no mention of it in the Pest Conditions Reports for those years. This outbreak affected about 1,000 acres. Populations were considered light and significant defoliation was not reported.

Tulare and Kern Counties: 1962 to1966. A 7,500 acre pandora moth infestation in Jeffrey pine stands was reported from the Taylor Meadow (Tulare County) and Bartolas (Kern County) areas on the Kern Plateau northeast of Lake Isabella in 1963 (CFPCAC, 1964). Based on reference to "pupal and egg counts taken in 1964", it is plausible that adult flight and egg deposition occurred in 1962. The 1964 Report also noted a moderate level of damage in localized centers of the infestation. This outbreak was recorded as continuing at low levels in the 1965 and 1966 Pest Conditions Reports.

Mono County: 1964 to1966. In 1965, a pandora moth infestation was reported affecting 1,000 acres in the Indiana Summit Natural Area on the Mono Lake District, Inyo National Forest,

Mono County (CFPCAC, 1966). Although not specifically referenced in previous conditions reports, the 1965 Report suggests the infestation had been detected, but not documented, in previous years. The infestation is noted as continuing at low levels in the Conditions Report for 1966.

Mono County: 1978 to1982. This outbreak was first detected in May 1979, in the vicinity of Lookout Mountain and the Crestview Rest Area on the Mammoth and Mono Lake Districts, Inyo National Forest (CFPCAC, 1979; USDA, 1979; Richers, 1985). The total area affected in 1979 was about 10,000 acres. Approximately 5,000 were already very heavily defoliated in 1979. This suggests that the outbreak started at least with adult flight in 1978 and it is possible that populations started to increase in 1976 but remained undetected until 1979. The outbreak ultimately affected about 16,240 acres with moderate to heavy defoliation (USDA, 1980). Increasing levels of nuclear polyhedrosis virus were detected in second and third stage larval populations collected in February, 1981 and populations declined in many areas, particularly where defoliation had been heavy (USDA, 1981a). No new areas of pandora moth activity or defoliation were detected in 1981 or 1982 (CFPCAC, 1982; 1983). A high incidence of nuclear polyhedrosis virus was again found in larval populations sampled in the fall of 1982 (USDA, 1982). The outbreak collapsed at the end of the third generation in 1983 when very few late-stage larvae were observed (CFPCAC, 1984).

Incidental Activity. California Forest Pest Conditions Reports document incidental pandora moth activity in Kern County in 1969 and in five counties between 1978 and 1985 (CFPCAC, 1970; 1979; 1980; 1983; 1986). The 1969 Conditions Report notes light pandora moth defoliation on Jeffrey pine from Rattlesnake Meadows in Kern County. This area, which actually appears to be in Tulare County, is within the vicinity of the 1962 to1966 Taylor Meadow-Bartolas infestation. Additional reports include "multiple sightings" in Kern County on Jeffrey pine, 1978; Tuolumne (Jeffrey pine) and Calaveras (ponderosa pine) Counties in 1979; Siskiyou County near Happy Camp (adults in light traps), 1982; and on Coulter pine in San Diego County in 1985.

Based on historical records, pandora moth outbreaks have occurred throughout the west at about 20 to 30 year intervals and have lasted for six to eight years (three to four generations) (Carolin and Knopf, 1968). A recent study using tree ring analyses on data from south-central Oregon, identified 22 outbreak periods over 622 years with a mean interval between outbreaks of 27 years (range of 8 to 48 years) and a mean duration of 10 years (range of 4 to 18 years) (Speer, 1997; Speer et al., 2001). Based on the documented outbreaks discussed above, outbreaks in California seem to occur at about 14 to 23 year intervals and last from four to six years (two to three generations).

Effects

Vegetation: The pandora moth affects host trees, in this case Jeffrey and lodgepole pine, through destruction of needles by larval feeding (defoliation) resulting in reduced amounts of foliage and photosynthetic capability. Feeding by the smaller, early stage larvae in late summer and fall results in less defoliation than feeding by the larger, late-stage larvae following year. Most of the

foliage is consumed by the third through fifth larval stages in the spring and early summer of the year after adult flight and egg deposition. Much of the feeding tends to be on older foliage and since the buds are not affected, trees are usually able to produce new foliage. The two year life cycle during which the second year is spent as non-feeding pupae in the soil, gives the host trees some time to recover and resume growth.

Depending on several factors, including the initial condition of the host tree, weather, and the frequency and amount of foliage loss, pandora moth defoliation can result in: 1) direct tree mortality; 2) secondary tree mortality due to loss of tree vigor and subsequent attack by bark beetles; and 3) growth loss. In general, the effects of pandora moth defoliation during past outbreaks have not been well quantified; the available information is summarized below.

1) Direct tree mortality due to the immediate effects of pandora moth defoliation has generally been considered of minor significance. Patterson (1929), reporting on the 1918 to1925 outbreak in southern Oregon that affected "thousands of acres", observed that direct mortality due to pandora moth feeding was minimal and of much less concern than secondary mortality due to bark beetle activity (see below). Direct mortality in the 100,000 acre outbreak on lodgepole pine in Colorado (1937 to1939) was concentrated on less than 0.6% of the infested area and estimated to involve 4,000 trees (Wygant, 1941). Sixty (3%) of 1,991 trees on research plots died during the same outbreak (Massey, 1940). Direct tree mortality associated with the 1978 to 1984 Arizona outbreak was estimated at less than 1% and considered insignificant (Bennett and Andrews, 1983; Bennett et al., 1987; Schmid and Bennett, 1988). Although overall mortality was low during this outbreak, defoliated ponderosa pines heavily infected with Southwestern Dwarf Mistletoe, *Arceuthobium vaginatum cryptopodum*, were more likely to die than uninfected trees and the probability of mortality resulting from pandora moth defoliation was greater in stands heavily infected with dwarf mistletoe (Wagner and Mathiasen, 1985; Schmid and Bennett, 1988).

2) Secondary mortality due to bark beetle activity, primarily the western pine beetle, *Dendroctonus brevicomis*, and the mountain pine beetle, *D. ponderosae*, was much greater than direct mortality following the 1918 to1925 outbreak in southern Oregon (Patterson, 1929). Beginning in 1923, bark beetle-related mortality increased in pandora moth defoliated stands but not in undefoliated areas. Mortality in a 2,000 acre area increased from 50 trees in 1923 (.025 trees/acre) to a total of 744 trees in 1926 (0.372 trees/acre). However, interpretation of these data is complicated by the additional influence of below normal precipitation (1922 to1924) in the area on tree vigor (Keen, 1937). Increased secondary mortality has not been reported following other pandora moth outbreaks, including the 1978 to1982 outbreak in Mono County.

3) Growth loss has been reported from several of the outbreaks. Patterson (1929) noted that during years of severe defoliation in Colorado, annual growth could be reduced as much as 80% and many trees failed to produce any new growth. Bennett and Andrews (1983) found a 25% reduction in basal area growth following two cycles of pandora moth defoliation during the Arizona outbreak (1979 and 1981). They also reported an additional 15% growth reduction in trees with dwarf mistletoe infections compared with uninfected trees. Bennett et al., (1987), reported that during the Arizona outbreak, periodic radial growth was about 10% less and periodic tree basal area growth about 15% less, in defoliated as compared to undefoliated areas.

In the same outbreak, Miller and Wagner (1989) found that tree growth was not linearly related to defoliation intensity although 83% of trees defoliated 76 to100 percent (heavy) and 24 % of trees defoliated 51 to75 percent (moderate) produced no growth the following year. Basal area growth was significantly lower in heavily and moderately defoliated trees during, and one year after, defoliation. Cochran (1998) documented a 25% reduction of annual basal area increments the first growing season after defoliation, a 30% decline the second year after defoliation and a 63% reduction following a second defoliation to pole-size ponderosa pine in central Oregon from 1988 to 1994. In a "level-of-growing-stock" study also in central Oregon, periodic annual increments were reduced for the 1991 to1995 growth period following moderate to heavy defoliation (Cochran, 1999). Radial growth remained reduced relative to pre-outbreak levels for at least 10 years following outbreaks in central Oregon (Speer, 2001).

Public Health and Safety: Although the spines on pandora moth late-stage larvae are urticating, they are quite flexible and generally do not cause stinging or skin irritation (Tuskes, 1984; Schmid and Bennett, 1988; Tuskes et al., 1996). Adult moths can be so numerous as to be a short-term, but considerable, nuisance and a possible safety hazard. Larvae can be a safety hazard if migrating in large numbers across trails, roads and highways.

Current Situation

A detection survey conducted on July 17 and 18, 2002, identified about 5,100 acres of pandora moth defoliation on lodgepole and Jeffrey pines of all size classes on the Mammoth and Mono Lake Districts (Fig. 1). The defoliation is currently concentrated in five areas, two in the general vicinity of Lookout Mountain (Lookout, 2,895 acres; Smoke, 759 acres) and three east and south of Wilson Butte (Tunnel, 861 acres; Aqueduct, 518 acres; Deadman, 91 acres). The defoliation is the result of feeding injury by larvae emerged from eggs deposited in July and August, 2001. The level of defoliation is "light", affecting less than 20 to 30 percent of the foliage on individual trees. Most of the injury is on the older foliage and generally concentrated in the upper one-half to one-third of the crowns. No pandora moth-related mortality was evident. No larvae were observed feeding on the foliage. A few dead larvae were seen on the surface of the soil/forest floor, apparently dying before they could burrow into the soil and pupate. Pupae were readily found in the soil indicating that the population had entered the overwintering stage.

Prognosis: Following is a brief description, based on historical documentation and current conditions, of what can reasonably be expected over the next few years. Barring an unexpected early population collapse, the current outbreak will likely continue for at least one to two, and possibly three, generations (two to six years). Populations will collapse due to a combination of natural factors, potentially involving the nuclear polyhedrosis virus. Given the current low levels of defoliation, some virus could be detected in the 2003 to 2004 larval populations (most likely in the late-stage larvae in the spring of 2004) but high levels of the virus may not be present (if at all) until the 2005 to 2006 generation.

Adult flight should occur in the summer of 2003 from late-June to September. Moths may be very numerous, readily noticeable and potentially disruptive in the short-term, particularly in areas near light sources. Larval activity will increase in late summer and fall of 2003 with increased defoliation becoming evident to some extent by late fall. The increased defoliation will become most noticeable in the spring and early summer of 2004 following late stage larval feeding. Historical records suggest that defoliation can be expected over at least 15,000 to 20,000 acres. Much of the increased defoliation will be in the general vicinity of areas currently affected but defoliation of additional new areas within the host type may occur. Affected areas may include high-use developed sites like the Crestview Roadside Rest Area, Inyo Craters Interpretive Site, Shady Rest and various other campgrounds as well as locations in and around the Town of Mammoth Lakes and the June Lake area.

Heavy defoliation affecting more than 75 percent of the crowns of individual trees will likely occur in relatively localized areas, particularly those experiencing repeated defoliation and in the vicinity of light sources. Extensive, widespread, direct mortality is not expected. Small group and scattered individual tree mortality may occur, especially in areas of repeated, heavy, defoliation. The level of secondary mortality is dependent on how much defoliation occurs, precipitation and local bark and engraver beetle activity levels. Growth loss and reduced tree vigor is expected and should be most pronounced in moderately and heavily defoliated trees. Below normal precipitation, particularly for an extended period, through added stress to host trees, would increase the chances of secondary mortality and the increase the effects of defoliation on individual trees. Also, the likelihood of mortality is greater for trees already under stress from other factors, such as overstocking, dwarf mistletoe infection or root disease.

Management Alternatives

Phytophagous insects may perform vital functions in forest ecosystem dynamics and defoliator outbreaks can be considered an integral component of forest change over time (Mattson and Addy, 1975; Torgersen, 2001). Any management response to the pandora moth outbreak depends to a considerable extent on a Forest/District assessment of the significance of pandora moth-related effects (positive and negative impacts) on ecological and resource management goals/ objectives and social and cultural values. Areas potentially affected by the pandora moth include, Vegetation Management, Fire and Fuels, Wildlife, Recreation and Social/Cultural/ Heritage resources.

There are technically several potential pandora moth direct and indirect management alternatives. There are a number of concerns associated with these options, including lack of specific efficacy data against pandora moth, implementation problems and/or questionable potential effects on other resources. Although it is not clear, given the likely biological effects of projected pandora moth defoliation, that any direct or indirect action against the pandora moth will be needed, following is a brief discussion of potential pandora moth management alternatives.

Insecticides: Insecticides are registered in California for use against invertebrates in coniferous forests. However, information on how effective the insecticides would be in reducing pandora

moth larval populations is very limited. It is also not known how varying levels of population reduction might affect subsequent levels of defoliation, tree mortality and growth loss and any resulting effects on unacceptable management impacts. Four insecticides (acephate, dimilin, malathion and carbaryl) were tested against pandora moth populations in Arizona in 1982 with mixed results (Ragenovich et al., 1982). An aerial suppression project using acephate to control pandora moth during the Arizona outbreak in 1983 was not effective in reducing tree mortality or growth loss (Bennett, et al., 1984; Bennett, et al., 1987; Schmid and Bennett, 1988) although the growth analysis did not take into account missing rings (Miller and Wagner, 1989).

Silviculture: Conversion of stands to non-pandora moth host tree species would be effective in preventing periodic outbreaks but has obvious practical considerations and implications for other resources. Thinning has been shown to be ineffective in the short-term in reducing pandora moth population densities (Ross, 1995). Defoliation has been observed to decrease as spacing in pole and small log sized ponderosa pine increased to about 24 feet (Cochran, 1998). However, the significance of unspecified levels of reduced defoliation on pandora moth impacts is unclear, optimal stocking levels for pandora moth management are not known and deviating from current desired stocking levels would have practical and other resource implications. Maintaining stands at currently desired stocking levels and reducing the incidence of disease, including dwarf mistletoe infections, should increase vigor and help reduced the effects of defoliation on individual trees.

Fire: As discussed above, fire has been documented to kill pandora moth larvae, pupae and adults. Other resource considerations notwithstanding, however, timely implementation of controlled burns over areas large enough, and at temperatures high enough, to kill enough overwintering pupae to significantly reduce subsequent resource impacts, is very conjectural. Larvae tend to pupate where litter is either nonexistent or less than 1.5 inches deep and fire generally does not heat the soil enough under such reduced fuel conditions to kill many pupae (Schmid et al., 1981; Schmid and Bennett, 1988). Prescribed burning would likely be effective only where substantial fuel is uniformly distributed throughout an area and, since pandora moths do not tend to pupate where adequate fuel loads occur, prescribed burning seems to have limited potential for controlling pandora moth populations (Miller and Wagner, 1984). The amount of pupal mortality needed to significantly reduce defoliation, tree mortality and/or growth loss (and presumably, unacceptable resource impacts) is not known. There are no efficacy data documenting the use of fire against the larval and adult stages to suppress pandora moth populations and, in any case, there would be problems of implementation.

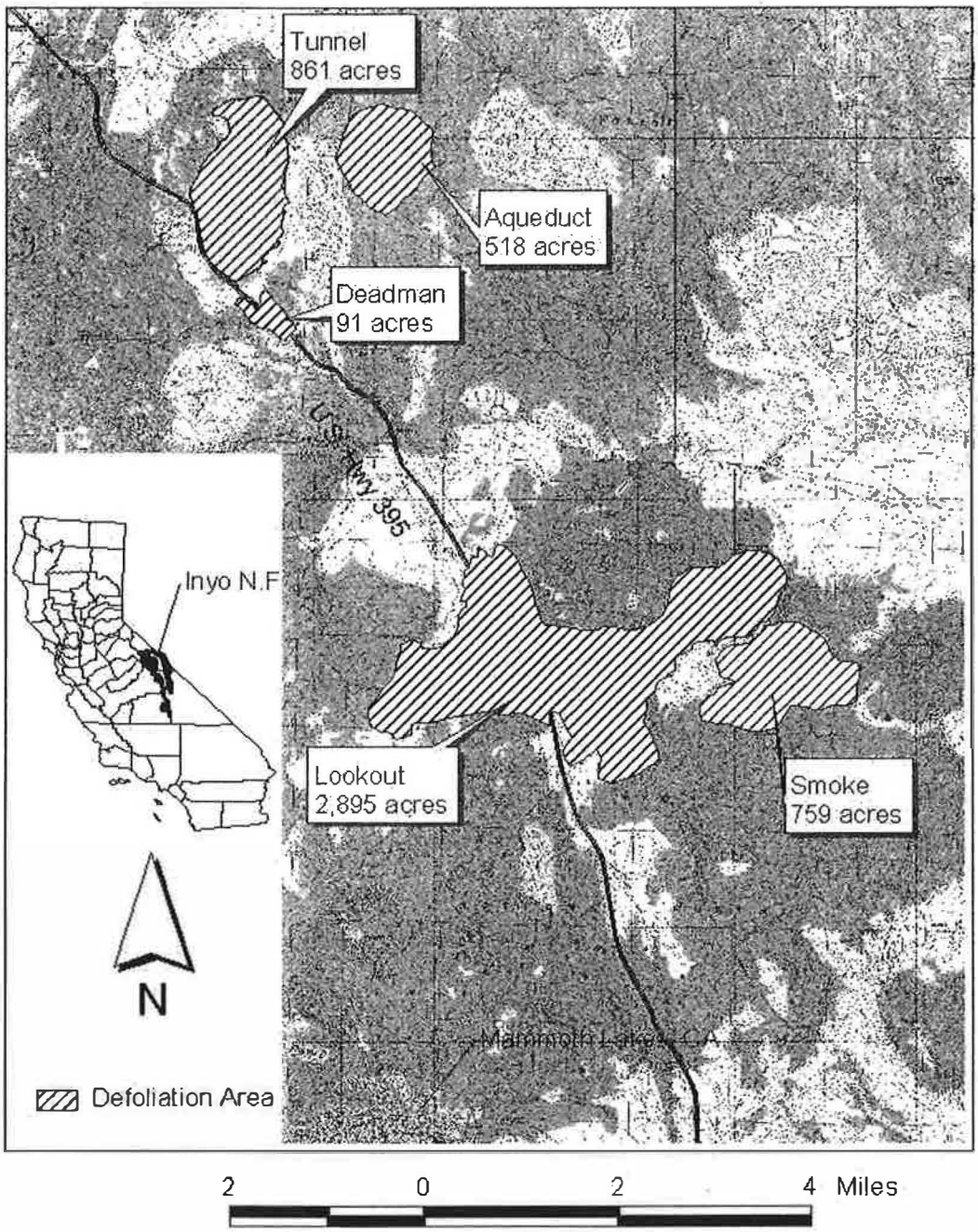
There are at least two additional alternatives that do not involve any direct or indirect action against the pandora moth; a "No Action" alternative and a proactive or "Informed Response" alternative.

No Action: Without direct intervention, the course of the outbreak and any ensuing effects will likely proceed as described in the "prognosis" section above. Adult moths will be numerous and conspicuous during the 2003 summer flight period. Additional defoliation will be evident in the fall of 2003 and become more noticeable in the spring and early summer of 2004. This alternative implies that no extra effort will be made to document and monitor pandora moth

activity or defoliation. Public interest in the pandora moth will increase in the summer of 2003, particularly during the adult flight period. Direct costs and impacts on time/ workforce management should be minimal except those associated with responding to increased public enquires. Responses to such enquires will not be based on updated, current information on the progress and status of the outbreak. Data on which to base timely management decisions that could become necessary throughout the course of the outbreak will not be available. Depending on the location and amount of defoliation and subsequent mortality, there may be a need to initiate salvage and/or hazard tree removal activities, perhaps as early as 2004 or 2005, with associated time and cost impacts.

Informed Response: The biological effects of the outbreak and the potential need for salvage and/or hazard tree removal activities are the same as in the No Action alternative. The main difference under this alternative is that some level of monitoring and documenting various aspects of the outbreak would be implemented and a proactive effort to inform the public about the outbreak would be undertaken. A study conducted on the North Rim of the Grand Canyon National Park during a pandora moth outbreak, suggested that an interpretive brochure helped visitors to be "more accepting" of National Park Service policies that allow "such phenomena to follow their natural course" (Richards et al., 1989). Monitoring efforts could include tracking and mapping areas of defoliation, measuring levels of defoliation, mortality, top-kill and growth loss on individual trees/stands and measuring various aspects of pandora moth population dynamics, including levels of the naturally occurring virus. Information from the various monitoring efforts would provide documentation of the outbreak for planning purposes and for making timely, informed, management decisions throughout the outbreak. It would also provide current, updated, information for knowledgeable responses to public enquires and could be of use in managing and responding to future pandora moth outbreaks. Implementation of monitoring activities will have associated costs and impact the time of Forest, District and FHP personnel.

Figure 1. Areas with Pandora Moth Defoliation:2002, Inyo NF, California.



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Literature

Aldrich, J.M. 1912. Larvae of a Saturniid Moth Used as Food by California Indians. Jour. N.Y. Entomol. Soc. Vol. XX: 28-30.

Aldrich, J.M. 1921. *Coloradia pandora* Blake, A Moth of Which the Caterpillar is Used as Food by Mono Lake Indians. Ann. Entomol. Soc. Amer. Vol. XIV: 36-38.

Bennett, D.D. and M.A. Andrews. 1983. Biological Evaluation- Pandora Moth, Kaibab National Forest, Arizona. USDA For. Serv. Southwestern Region FPM Rpt. R3 83-7. 15pp.

Bennett, D.D., Wahlfeld, D.R., and J.M. Schmid. 1984. Pandora Moth Suppression Project Using Acephate, Jacob Lake, Arizona, 1983, 1984. USDA For. Serv. Southwestern Region FPM Rep. R-3 84-10. 18 pp.

Bennett, D.D., Schmid, J.M., Mata, S.A. and C.B. Edminster. 1987. Growth Impact of the North Kaibab Pandora Moth Outbreak. USDA For. Serv. Res. Note RM-474. 4 pp.

Blake, E.A. and M.R. Wagner. 1987. Collection and Consumption of Pandora Moth, *Coloradia pandora lindseyi* (Lepidoptera: Saturniidae), Larvae by Owens Valley and Mono Lake Piutes. Bull. ESA, Spring 1987: 23-27.

Brown, L.N. 1984. Population Outbreak of Pandora Moths (Coloradia Pandora Blake) On The Kaibab Plateau, Arizona (Saturniidae). Jour. Lepidopterists' Soc. 38 (1): 65.

California Forest Pest Control Action Council. 1964. Forest Pest Conditions in California-1963. Duplicated and Distributed by the Calif. Div. For. 20 pp.

California Forest Pest Control Action Council. 1965. Forest Pest Conditions in California-1964. Duplicated and Distributed by the Calif. Div. For. 20 pp.

California Forest Pest Control Action Council. 1966. Forest Pest Conditions in California-1965. Duplicated and Distributed by the Calif. Div. For. 20 pp.

California Forest Pest Control Action Council. 1967. Forest Pest Conditions in California-1966. Duplicated and Distributed by the Calif. Div. For. 21 pp.

California Forest Pest Control Action Council. 1970. Forest Pest Conditions in California-1969. Duplicated and Distributed by the Calif. Div. For. 21 pp.

California Forest Pest Control Action Council. 1979. Forest Pest Conditions in California-1978. Duplicated and Distributed by the Calif. Div. For. 23 pp.

California Forest Pest Control Action Council. 1980. Forest Pest Conditions in California-1979. Duplicated and Distributed by the Calif. Div. For. 24 pp.

California Forest Pest Control Action Council. 1981. Forest Pest Conditions in California-1980. Duplicated and Distributed by the Calif. Div. For. 28 pp.

California Forest Pest Control Action Council. 1982. Forest Pest Conditions in California-1981. Duplicated and Distributed by the Calif. Div. For. 30 pp.

California Forest Pest Control Action Council. 1983. Forest Pest Conditions in California-1982. Duplicated and Distributed by the Calif. Div. For. 28 pp.

California Forest Pest Control Action Council. 1984. Forest Pest Conditions in California-1983. Duplicated and Distributed by the Calif. Div. For. 28 pp.

California Forest Pest Control Action Council. 1986. Forest Pest Conditions in California-1985. Duplicated and Distributed by the Calif. Div. For. 24 pp.

Carolin, V.M. Jr. 1971. Extended Diapause in *Coloradia pandora* Blake (Lepidoptera: Saturniidae). Pan-Pac. Entomol. 47: 19-23.

Carolin, V.M. Jr. and J.A.E. Knopf. 1968. The Pandora Moth. USDA For. Serv. Forest Pest Leaflet 114: 1-7.

Chamberlin, W.J. 1922. A New Lepidopterous Enemy of Yellow Pine in Oregon. Jour. N.Y. Entomol. Soc. Vol. XXX: 69-71.

Ciesla, W.M., Bennett, D.D. and J.A. Caylor. 1984. Mapping Effectiveness of Insecticide Treatments Against Pandora Moth with Color-IR Photos. Photogrammetric Engineering and Remote Sensing 50 (1): 73-79.

Cochran, P.H. 1998. Reduction in Growth of Pole-Sized Ponderosa Pine Related to a Pandora Moth Outbreak in Central Oregon. USDA For. Serv. Res. Note PNW-RN-526. 14 pp.

Cochran, P.H. and J.W. Barrett. 1999. Growth of Ponderosa Pine Thinned to Different Stocking Levels in Central Oregon: 30-Year Results. USDA For. Serv. Res. Paper PNW-RP-508. 27 pp.

Fitzgerald, S.A. 1992. Controlling Pandora Moth in Central Oregon Forests and Landscapes. Oregon State Extension Serv. Circular EC-1383. 4 pp.

Fowler, C.S. and N.P.Walter. 1985. Harvesting Pandora Moth Larvae with the Owens Valley Paiute. Jour. Calif. and Great Basin Anthropology 7 (2): 155-165.

Furniss, R.L. and V.M. Carolin. 1977. Western Forest Insects. USDA For. Serv. Misc. Publ. 1339: 193-196.

Gerson, E.A. and R.G. Kelsey. 1997. Attraction and direct mortality of pandora moths, *Coloradia pandora* (Lepidoptera: Saturniidae), by nocturnal fire. Forest Ecology and Management 98: 71-75.

Gerson, E.A., Kelsey, R.G., McComb, W.C. and D.W. Ross. 1998. Palatability of *Coloradia pandora* (Lepidoptera: Saturniidae) Eggs to a Rodent Predator: Contributions of Physical and Chemical Characteristics. Envir. Entomol. 27 (3): 709-716.

Gerson, E.A., Kelsey, R.G. and D.W. Ross. 1999. Pupal Diapause of *Coloradia pandora* Blake (Lepidoptera: Saturniidae). Pan-Pac. Entomol. 75(3): 170-177.

Hughes, K.M. 1977. Observations on the Morphology of Nuclear Polyhedrosis Viruses From Six Forest Insects. Can Entomol. 109 (5): 759-762.

Keen, F.P. 1937. Climatic Cycles in Eastern Oregon as Indicated by Tree Rings. Monthly Weather Review. 65(5): 175-188.

Keen, F.P. 1952. Insect Enemies of Western Forests. USDA Misc. Pub. No. 273: 83-85.

Lemaire, C. and M.J. Smith. 1992. A New Species of *Coloradia* From Sonora and Chihuahua, Mexico (Saturniidae: Hemileucinae). Jour. Lepidopterists' Soc. 46(2): 128-137.

Lyon, R.L. 1971. Contact Toxicity of 40 Insecticides Tested on Pandora Moth Larvae. USDA For. Serv. Res. Note PSW-235. 4 pp.

Massey, C.L. 1940. The Pandora Moth, (*Coloradia pandora* Blake), a Defoliator of Lodgepole Pine in Colorado. Unpub. M.A. Thesis, Duke Univ., Raleigh, NC. 33 pp.

Mattson, W.J. and N.D. Addy. 1975. Phytophagous Insects As Regulators of Forest Primary Production. Science 190 (4214): 515-522

McElfresh, J.S., Chen, X., Ross, D.W. and J.G. Millar. 2000. Sex Pheromone Blend of the Pandora Moth (Lepidoptera: Saturniidae), An Outbreak Pest in Pine Forests (Pinaceae). Can. Entomol. 132 (6): 775-787.

Miller, K.K. and M.R. Wagner. 1984. Factors Influencing Pupal Distribution of the Pandora Moth (Lepidoptera: Saturniidae) and Their Relationship to Prescribed Burning. Envir. Entomol. 13: 430-431.

Miller, K.K. and M.R. Wagner. 1989. Effect of Pandora Moth (Lepidoptera: Saturniidae) Defoliation on Growth of Ponderosa Pine in Arizona. J. Econ. Entomol. 82 (6): 1682-1686.

Mitchell, R. 1989. The Pandora Moth Is Coming To Central Oregon. Cascades East 14: 55-56.

Patterson, J.E. 1929. The Pandora Moth, A Periodic Pest of Western Pine Forests. USDA Tech. Bull. No. 137. 20 pp.

Ragenovich, I.R., Schmid, J.M., Bennett, D.D., Barry, J.W. and C.E.Richmond. 1986. Field evaluations of four insecticides against the Pandora moth. Ent. Soc. Amer., Insecticide and Acaricide Tests 11: 426.

Richards, M.T., Wagner, M.R., Daniel, T.C. and T.C. Brown. 1989. Impact of Pandora Moth Defoliation on Scenic Quality and Recreation Value of a Forested Area. Unpub. Rpt., USDA For. Serv. Rocky Mountain For. & Range Exp. Station. 33pp.

Richers, K. 1985. Population Outbreak of Pandora Moths (*Coloradia pandora* Blake) in the Mammoth Lakes Area, California. Jour. Lepidopterists' Soc. 39(4): 338-339.

Ross, D.W. 1995. Short-Term Impacts of Thinning Ponderosa Pine on Pandora Moth Densities, Pupal Weights, and Phenology. West. J. Appl. For. 10 (3): 91-94.

Ross, D.W. 1996. Phenology of Pandora Moth (Lepidoptera: Saturniidae) Adult Emergence and Egg Eclosion in Central Oregon. Pan-Pac Entomol. 72 (1): 1-4.

Schmid, J.M. 1984. Emergence of Adult Pandora Moths in Arizona. Great Basin Nat. 44(1): 161-165.

Schmid, J.M., Thomas, L. and T.J. Rogers. 1981. Prescribed Burning to Increase Mortality of Pandora Moth Pupae. USDA For. Serv. Res. Note RM-405. 3 pp.

Schmid, J.M., Farrar, P.A. and J.C. Mitchell. 1982. Distribution of Pandora Moth Egg Masses and Pupae near Jacob Lake, Arizona. Envir. Entomol. 11(3): 701-704.

Schmid, J.M., Bennett, D., Young, R.W., Mata, S., Andrews, M., and J. Mitchell. 1982. Sampling Larval Populations of the Pandora Moth. USDA Res. Note RM-421. 5 pp.

Schmid, J.M., Bennett, D.D. and M. Andrews. 1983. Distribution of Pandora Moth Egg Masses and First Stage larvae. USDA For. Serv. Res. Note RM-432. 4 pp.

Schmid, J.M. and D.D. Bennett. 1988. The North Kaibab Pandora Moth Outbreak, 1978-1984. USDA For. Serv. Gen. Tech. Rpt. RM-153. 18 pp.

Schmid, J.M. and S.A. Mata. 1996. Natural Variability of Specific Forest Insect Populations and Their Associated Effects in Colorado. USDA For. Serv. Gen. Tech. Rep. RM-GTR-275. 14 pp.

Speer, J.H. 1997. A Dendrochronological Record of Pandora Moth (*Coloradia pandora*, Blake) Outbreaks in Central Oregon. Unpub. M.S. Thesis, Univ. of Arizona, Tucson. 159 pp.

Speer, J.H., Swetnam, T.W., Wickman, B.E., and A. Youngblood. 2001. Changes in Pandora Moth Outbreak Dynamics During the Past 622 Years. Ecology 82(3): 679-697.

Torgersen, T.R. 2001. Defoliators in Eastern Oregon and Washington. Northwest Science, Vol. 75, Special Issue: 11-20.

Tuskes, P.M. 1984. The Biology and Distribution of California Hemileucinae (Saturniidae). Jour. Lepidopterists' Society 38(4): 281-309.

Tuskes, P.M., Tuttle, J.P. and M.M. Collins. 1996. The Wild Silk Moths of North America: A Natural History of the Saturniidae pf the United States and Canada. Comstock Pub. Assoc. (Cornell Univ. Press). 239 pp.

USDA Forest Service. 1960. Forest Insect Conditions, Southern California, June 1960. Pacific Southwest Forest and Range Experiment Station, Division of Forest Insect Research, Unnumbered Report (5230, July 27, 1960, R.C. Hall). 7 pp.

USDA Forest Service. 1979. Biological Evaluation of Mammoth and Mono Lake Ranger Districts. Pacific Southwest Region R5 3430 FIDM Eval. Rpt. 5 pp.

USDA Forest Service. 1980. Pandora Moth Outbreak on the Mammoth and Mono Lake Ranger Districts. Pacific Southwest Region R5 FPM 3430 Eval. Rpt. 5 pp.

USDA Forest Service. 1981a. Pandora Moth Outbreak on the Mammoth and Mono Lake Ranger Districts. Pacific Southwest Region R5 FPM 3430 Eval. Rpt. 3 pp.

USDA Forest Service. 1981b. Environmental Assessment for the Pandora Moth Outbreak 1980-81 Generation on the Mammoth and Mono Lake Ranger Districts, Inyo National Forest, Mono County, California. Pacific Southwest Region Envir. Assess. 19 pp.

USDA Forest Service. 1981c. Final Environmental Impact Statement, Pandora Moth Management Plan, Kaibab National Forest, Coconino County, Arizona. Southwestern Region Rpt. 03-07-81-1. 89 pp.

USDA Forest Service. 1982. Unpublished Data. Forest Health Protection, Pacific Southwest Region. 1 p.

USDA Forest Service. 1983. Biological Evaluation- Pandora Moth. Southwestern Region R3 For. Pest. Mgt. Rpt. 83-7. 15 pp.

Wagner, R.W. and R.L. Mathiasen. 1985. Dwarf Mistletoe-Pandora Moth Interaction and It's Contribution to Ponderosa Pine Mortality in Arizona. Great Basin Naturalist 45(3): 423-426.

Weaver R.A. and M.E. Basgall. 1986. Aboriginal Exploitation of Pandora Moth Larvae in East-Central California. Jour. Calif. and Great Basin Anthropology 8(2): 161-179.

Wickman, B.E., Mason, R.R. and H.G. Paul. 1996. Ponderosa Pine Response to Nitrogen Fertilization and Defoliation by the Pandora Moth, *Coloradia pandora* Blake IN: Dynamics of Forest Herbivory: Quest for Pattern and Principle, Mattson, W.J., Niemela, P., and N. Rousi, eds. USDA For. Serv. Gen. Tech. Rep. NC-183: 118-126.

Wygant, N.D. 1941. An Infestation of the Pandora Moth, *Coloradia pandora* Blake, in Lodgepole Pine in Colorado. Jour. Eco. Entomol. 34(5): 697-702.